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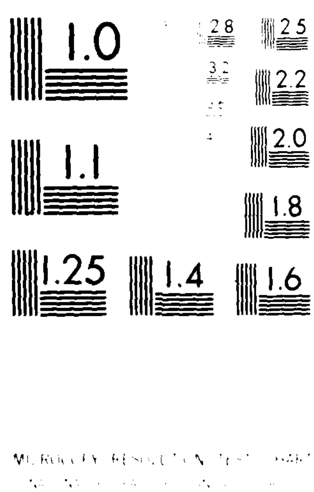
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DOES DUAL-AXIS TRACKING DEMAND MORE RESOURCES THAN SINGLE-AXIS TRACKING?

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ABSTRACT

Earlier studies (Gopher & Navon, in press) indicated that when control dynamics is simple, vertical and horizontal tracking interfere very little with each other. The present study was designed to test in a systematic way the possible effects of three elements in a dual-axis tracking situation: the addition of an axis in itself, the presence of visual feedback-indicators, and the requirement to allocate resources unevenly between the axes. Practiced subjects were required to make binary classification of visually presented digits while tracking; digits were presented within a moving square that served as the target for tracking. Small dual-task deficits were found in the performance of both tracking and digit classification. Their small extent suggests that we succeeded to eliminate a major source of structural conflict. The condition of tracking did not have a discernible effect on either task. Hence, the introduction of a second tracking axis probably does not have harmful consequences either on tracking itself or on any other task time-shared with tracking. The results are interpreted within the framework of a multiple resource approach (Navon & Gopher, 1979).

Does Dual-Axis Tracking Demand More Resources Than Single-Axis Tracking?

The requirement in a two-dimensional pursuit tracking task in which the controlled symbol and the target symbol are displayed on a screen is to minimize Euclidian distances between these symbols. Nevertheless, it may be regarded as composed of two separate component tasks, that of minimizing distances along the horizontal axis, and that of minimizing distances along the vertical axis. That this is a viable description of the psychological process underlying performance is suggested by several findings in the literature (e.g., Gopher, Williges, Williges and Damos, 1975; Levison, Elkind & Ward, 1971; Poulton, 1974, ch. 12; Onstott, 1976).

Regardless of whether subjects naturally treat two-dimensional tracking as a combination of two tasks, they may be induced to do it by separating the feedback on their performance on the two axes and asking them to adapt their performance on the two axes to independent performance requirements. The results of Gopher & Navon (in press) indicate that subjects were able to respond to the two axes independently.

Given that two-dimensional tracking is a dual-task situation, at least in such experimental conditions, the question arises of whether the two tasks involved, namely horizontal and vertical tracking, interfere with each other. We recently found (Gopher & Navon, in press) that when required to control primarily the velocity of the controlled symbol, trained subjects could perform in such a situation with little or no interference between the axes. We were quite confident that this could not be explained on the grounds that the tasks were too easy. For example, in the condition in which equal emphasis was put on the performance of both axes, a subject had to perform on each axis at or above his median performance during a preliminary session, in which he had been required to do his utmost. Second, the tasks did not interfere more the more difficult they were (when difficulty was manipulated through the frequency or velocity of target movements).

Thus, we were led to the conclusion that vertical and horizontal tracking do not compete very much for processing resources. In the spirit of the notion of multiple resources which we discussed elsewhere (Navon & Gopher, 1979; Navon & Gopher, in press), we speculated that perhaps despite their apparent similarity, those tasks do not call for exactly the same type of resource. Does the negligible interference we found between tracking axes entail that whenever control dynamics is simple dual-axis tracking does not impose on the system a heavier load than single-axis tracking does? Not necessarily. First, although each tracking dimension may be costless in terms of performance on the other one, it may still be in conflict with some other task which depends on the same pool of resources. Second, and perhaps more reasonable a priori, the coordination of two tasks may tax more mechanisms that may not be relevant for the performance of each of the tasks in itself, yet may be relevant for the performance of some other task (see Navon & Gopher, 1979, p. 241).

To support such conjectures one should look for evidence that the performance of certain tasks deteriorates more when paired with dual-axis tracking than when paired with either vertical tracking or horizontal tracking. We reasoned that a likely candidate for manifesting such an effect could be a task which seems to be associated with a high cognitive load and that requires a manual response[1]. Accordingly, we had subjects make varied-mapping binary classification of digits while tracking in one or two dimensions. Performance under those dual-task conditions was to be compared with performance of both tasks (tracking or digit classification) in a single-task situation[2]. In addition, we manipulated the difficulty of the digit task by varying the memory load it imposed on the subjects.

Several elements in the dual-axis tracking situation could potentially contribute to make its load higher than the load imposed by single-axis tracking. First, of course, is the addition of a tracking dimension (or alternatively, the higher uncertainty about orientation of motion). Second is the presence of bar graphs which served as feedback indicators (see Method section): It might be argued that feedback, however useful it is, consumes more resources by virtue of the extra visual and cognitive processing it requires. Third is the need to allocate resources in uneven, thus perhaps unnatural, proportions between the two axes to meet performance requirements that assign to them unequal priorities. To test the unique contribution of each of these elements, we designed conditions which included one, two or all three of them. In other words, there were three modes of dual-axis tracking in this experiment: one, without any feedback indicator and no explicit performance requirement; two, with feedback indicators and equal priorities on the axes; three, with feedback indicators and unequal priorities on the axes.

Since we were looking for capacity interference we had to be careful to eliminate all other possible sources of interference. One thing that could have happened in such a task combination is that the digit task suffered when time-shared with tracking because the digits were then viewed peripherally more frequently. To guard against such an effect, digits were presented within a square that served also as the target symbol for the tracking task (see illustration in Figure 1).

Insert Figure 1 about here

Method

Experimental tasks. The experiment was conducted individually. Subjects were seated at a distance of approximately 70 cm from a GT 42 graphic display. A square measuring 1.5 cm (1.2° visual angle) in height and width moved continuously on the screen, driven by random, band-limited forcing functions generated by a PDP 11/45 computer. The square could move in one dimension, vertical or horizontal, only, or in both simultaneously. Its range of movement in each dimension was 20 cm (16° visual angle). That square served as the target symbol for a pursuit tracking task, in which subjects had to pursue the target by moving a control symbol (a 1.5 cm high X character) on the screen so as to minimize the distance between the two symbols. The control symbol was controlled using a single, two-dimensional spring-loaded hand controller operated by the subject's right hand. Right and left deflections of the hand controller moved the X on the screen in the horizontal axis while fore and aft deflections were translated to up and down movements on the screen respectively. Control dynamics was a mixture of 80% velocity and 20% acceleration. In other words, hand controller deflections did not affect the position of the X on the screen directly, but rather changed the velocity and acceleration components of its movement with a greater emphasis on velocity (for more details see Gopher & Navon, in press). Subjects could be presented with an on-line, continuous feedback on their tracking performance. Feedback indicators (one for each axis) comprised a short, static, horizontal line and a

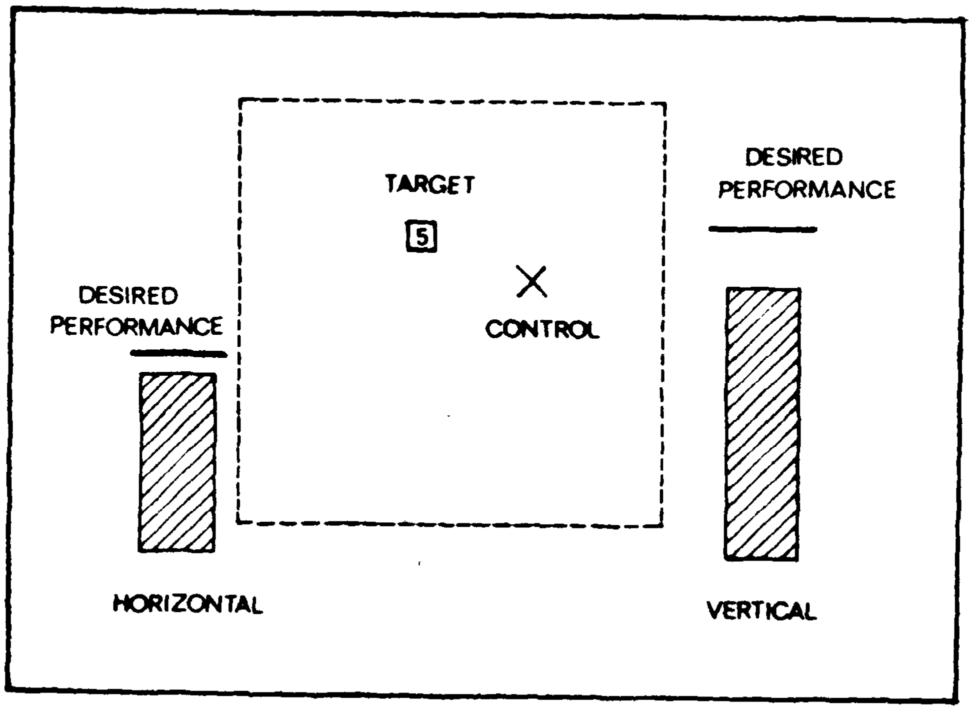

Figure 1: A schematic drawing of the display with the feedback indicators and a digit presented.

moving vertical bar-graph. The static line represented the desired level of performance (in terms of tracking error), which was determined in reference to a normalized baseline distribution of performance obtained for each subject at a calibration session which took place prior to the practice and experimental sessions (see Procedure). Subjects were instructed to perform at that level or better. The height of the moving bar-graphs reflected the momentary difference between actual and desired performance. This difference was computed continuously by subtracting the momentary error score from the desired score and dividing the outcome by the standard deviation of the baseline distribution. Dimension priorities could be manipulated by changing the required level of tracking accuracy on each dimension, and displayed by changing the relative height of the desired performance lines.

The digits which subjects were asked to classify were generated randomly by the computer and were presented each for 300 msec within the moving target square, and masked by a pattern of horizontal and slightly diagonal lines; that pattern appeared within the square for the whole interstimulus interval which was 1200 msec. Subjects had to classify the digit presented into one of two sets priorly defined and to indicate their classification by pressing one of two pushbuttons with two fingers of their left hands. Errors and latencies of classification as well as accuracy of tracking were recorded by the computer.

Procedure and design. Each subject participated in four two-hour sessions, no two of which were ever held on the same day. The first two sessions were training and calibration sessions, namely they were designed to familiarize the subject with each of the tasks and their combinations, to train him under increased levels of tracking difficulty (manipulated through the frequency and speed of target movements on the screen), so as to obtain the individual level of difficulty at which his performance was stable, and to obtain an individual tracking performance baseline distribution to be used later in order to feed back to the subject the momentary adequacy of his performance (see <u>Experimental tasks</u>).

The last two sessions had the same structure, but only data from the last of those (namely, the fourth session) were analyzed; the other session was considered as practice session. Each of those two sessions consisted of twenty three-minute trials separated by three-minute periods of rest. In half of the trials the subject was just required to track. In the rest of the trials he had to perform the digit task as well. Each of these halves was evenly divided in five tracking conditions: (a) horizontal tracking only; (b) vertical tracking only; (c) dual-axis tracking without feedback indicators and no explicit performance requirements; (d) dual-axis tracking with feedback indicators and equal priorities on the axes; (e) dual-axis tracking with feedback indicators and unequal priorities (.65 on the vertical axis). The order of presentation of the trials was different for each subject. All the ten different treatments were administered once in a certain order at the first half of a session, and then replicated in a different order at the second half.

Memory load of the digit task was manipulated between subjects. Five subjects had to classify four digits in two sets of two digits each; five other subjects had to classify six digits in sets of three digits each. The sets could be changed from trial to trial and were introduced to the subject before the trial. Five different set pairs for each subject-group were used in a random order.

Subjects. Ten subjects participated in the experiment, all of them male right-handed students of the Technion-Israel Institute of Technology. They were paid for their participation on an hourly basis.

Results

The digit task performance measures were percentages of correct digit responses and mean latency. (Eyeball inspection indicated that mean latency for correct responses only does not depart much from mean latency computed across all responses.) The tracking performance measure was root mean square (RMS) tracking error on each tracking dimension. Root mean square is a weighted score that assigns greater weight to larger errors. Errors on each axis were measured every 60 msec, expressed as percent of maximum scale, and integrated over 15-sec intervals. The 12 values obtained in this manner for each 3-minute trial were averaged to yield an overall performance score for that trial.

The arcsine square root transforms of percentages of correct digit responses were subjected to a two-way ANOVA, factors of which were memory load and tracking condition (data from both vertical and horizontal tracking conditions were collapsed). A similar analysis was conducted on the latencies of digit responses. Three three-way ANOVAs were conducted on horizontal RMS error, vertical RMS error, and their average. The additional factor was whether tracking was done with or without a concurrent digit task.

Strangely enough, in none of these analysis was there a significant effect of memory load, neither did it interact significantly with any other factor. This is probably not due to the small power of the statistical test, because the subjects who were given the higher load performed even slightly better. The only plausible explanation we can think of is that those subjects were simply more competent. In any event, this result justified the presentation of further analyses without any reference to differences between memory load groups.

Most of the relevant data are presented in Figure 2. The results of the separate analyses of RMS errors in each of the axes are not

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Insert Figure 2 about here

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presented here because they were not notably different from the results of the analysis of RMS error averaged over the axes.

A small (1.7%) but significant ($F(1,8) = 11.71$; $p < .01$) increase in RMS error was observed when the subjects had to perform the digit task in addition to tracking (see Figure 2B). There was no main effect of the factor of tracking condition ($F(3,24) < 1$) nor did it interact with the dual-task requirement ($F(3,24) = 1.17$; $p > .25$). Nevertheless, since we set out to test the effects of three elements in dual-axis tracking, we conducted planned pairwise comparisons between the means of the various tracking conditions: a & b vs. c to test the effect of the addition of a tracking dimension; c vs. d to test the effect of feedback; and d vs. e to test the effect of unequal priorities. We analyzed both tracking error in the single-task situation (namely, when the subject had to do just tracking), and increase of tracking error due to the dual-task requirement. None of the comparisons yielded a significant result. It is also noteworthy that the performance of subjects along either of the axes in themselves did not change from condition d to condition e, which suggests that they did not try or did not succeed in emphasizing one axis over the other.

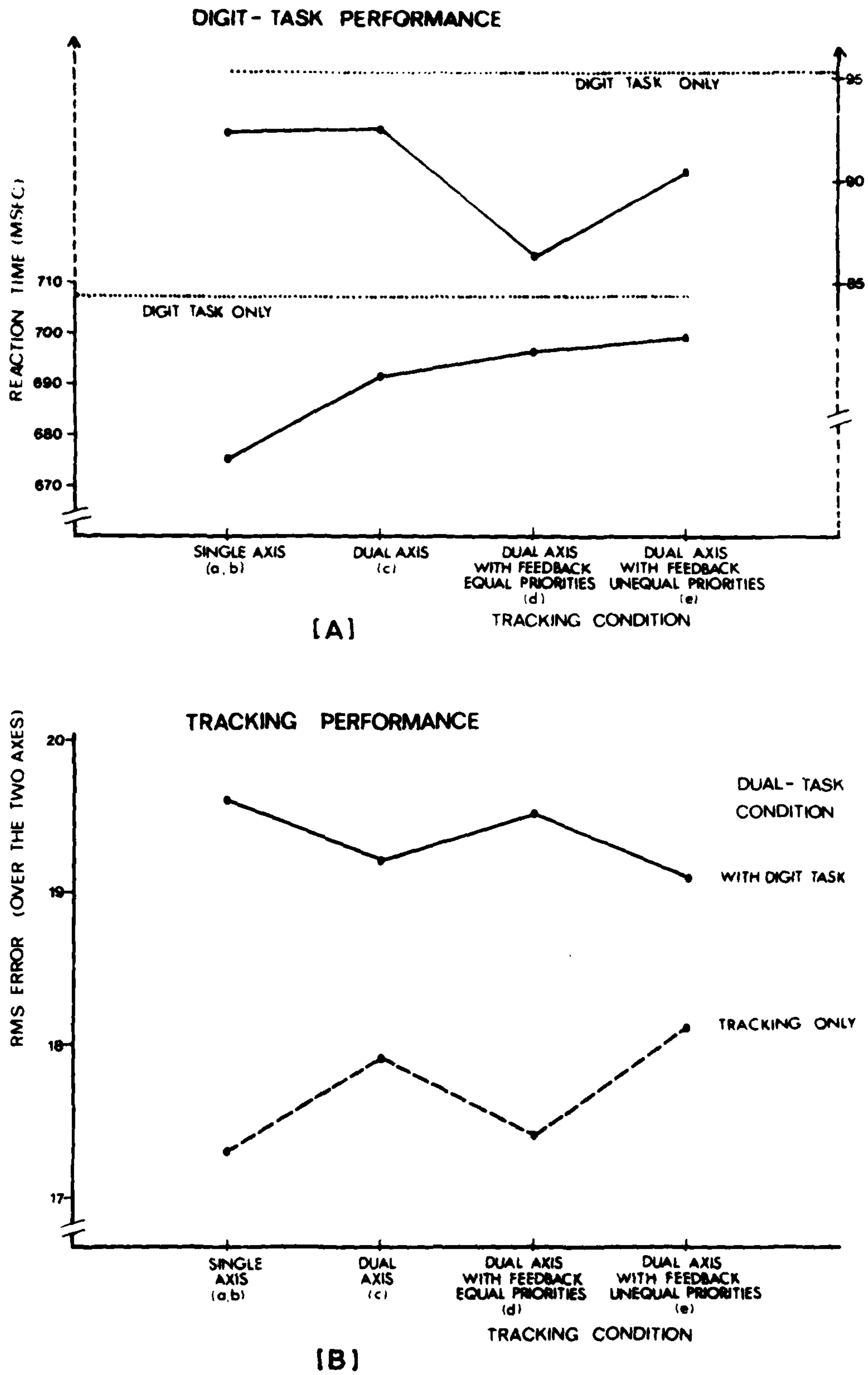

Figure 2: Performance in the two tasks as a function of tracking condition. Both single-axis conditions are collapsed. Panel A presentes percentages of correct digit responses and mean latencies. Dotted lines represent performance when the digit task was performed as a single task in the second calibration session. Panel A presents RMS error (percent of scale) averaged over the two axes, separately for the single-task and for the dual-task situation.

A similar picture emerged from the analysis of the digit task performance (see Figure 2A). Single-task data (namely when no tracking was required) were available only from the training session, so a possible order effect could probably have worked only in favor of performance in the dual-task situation. Still small (4.8%), but significant ($t(9) = 2.41$; $p < .05$) decrement in accuracy was observed when tracking was added. A concomitant small decrease in latency (16 msec) that could have indicated to a speed-accuracy tradeoff was not found significant ($F(1,8) = 2.21$; $p > .10$).

Tracking condition was observed to affect accuracy ($F(3,24) = 3.11$; $p < .05$) but not latency ($F(3,24) = 1.91$; $p > .10$). Pairwise comparisons revealed that the effect on accuracy resides in the introduction of feedback indicators ($t(9) = -2.59$; $p < .05$) which resulted in a rise in digit classification errors. A 16 msec increase in latency from the single- to dual-axis condition was not found significant ($t(9) = 1.38$; $p > .20$). If it nevertheless reflects a real difference, this must be due to a slight shift in allocation criterion in favor of tracking, since it is accompanied by a small, though nonsignificant, improvement in tracking accuracy.

Discussion

The performance of both the digit task and the tracking task were impaired by pairing them in a dual-task situation. This suggests that they conflict in some way or another: they either compete for resources, or they suffer from what we elsewhere called *concurrence cost* (Navon & Gopher, 1979), namely from main or side effects of the performance of one task that make the other one more difficult. However, the dual-task deficit was small relative to some deficits in similar studies reported in the literature (Gopher & North, 1977; Huddleston & Wilson, 1971; Wickens & Gopher, 1978). One possible cause for this discrepancy is that our subjects were very trained: they started the experimental session after having practiced for 240 minutes of net practice, 42 of which under the dual-task requirement. Another likely explanation is that our method of presenting the digits eliminated a major source of structural conflict between the tasks, namely the need to split on the services of the fovea which might arise if digits are presented at a fixed location, say at the bottom of the display (see, e.g., Gopher & North, 1977). The importance of the latter point cannot be exaggerated. It warns that one should be very hesitant to admit attempts to explain dual-task deficits in terms of capacity interference without substantive evidence that some proven sources of concurrence cost (e.g., competition for retinal resolution) have been eliminated.

By and large, the conditions of tracking did not seem to affect the performance of either task. The addition of a second axis of tracking did not affect either the quality of tracking performance on the first axis or the speed or the accuracy of concurrent digit classification. Feedback indicators were not shown here to be of much help to tracking; on the other hand, they seem to have caused some decrement in classification accuracy, probably because visual processing of the digits and the information conveyed by the indicators compete for visual resolution. Overall performance was not affected by whether the same or different priorities were put on the two axes of tracking. But this may be due to the failure of the subjects to comply with the priority instructions which were observed in the single-axis tracking data.

These results constitute further evidence for what we had already pointed to (Gopher & Navon, in press), namely that the accuracy of tracking in one of the axes is hardly affected by whether or not the subject is to track in the other axis as well. Furthermore, dual-axis tracking seems not to be more costly than single-axis tracking even in terms of other resources which are not used for tracking on either of the axes.

If the coordination between the axes consumed some resource on which digit classification also depended, then either tracking or digit performance would be worse in the dual-axis than in the single-axis condition. However, no such effect was observed. Thus, there is no evidence that dual-axis tracking with the parameters used in this study is more demanding than single-axis tracking, neither in tracking performance itself, nor in the performance of a concurrent digit task[3]. Granted, it is still possible that such an evidence will be found through using a different sort of concurrent task or a more powerful test. We presently tend to doubt it. First, our intuition suggests that if supervision and coordination of motor responses are high-level cognitive functions, they must resort to some resources in common with digit classification. Second, we cannot even point to a trend that may have been masked by error variance and that could be better detected by a more powerful statistical test or a more sensitive experimental procedure. The only way we see to reconcile our negative result and subjects' reports of a heavier load felt during dual-axis tracking is that indeed the processing system is busier when two axes are being tracked: more mechanisms are being engaged, more resources are used, but not of the kind that could have been invested to improve the performance of a single-axis tracking. Adding an axis activates a different pool of resources, that may have been idle when tracking was done on the other axis alone, because it is irrelevant for the performance of tracking on that axis.

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Footnotes

1. The rationale is justified by a recent finding of considerable interference between tracking and choice RT task when responses are manual, but not when they are vocal (McLoed, 1978).

2. In this paper we reserve the term dual-task to the condition in which subjects were required both to track and respond to digits. When subjects are just to track on both dimensions, they are said to be involved in a single-task condition in which they perform dual-axis tracking.

3. Note that the tracking task as employed in the present experiment is a quite common variant of a manual controller which represents a large set of real-system control devices, in which an element is simply controlled in an environment of increased external demands.

Figure Captions

Figure 1: A schematic drawing of the display with the feedback indicators and a digit presented.

Figure 2: Performance in the two tasks as a function of tracking condition. Both single-axis conditions are collapsed. Panel A presents percentages of correct digit responses and mean latencies. Dotted lines represent performance when the digit task was performed as a single task in the second calibration session. Panel A presents RMS error (percent of scale) averaged over the two axes, separately for the single-task and for the dual-task situation.

DOES DUAL-AXIS TRACKING DEMAND

MORE RESOURCES THAN SINGLE-AXIS TRACKING?

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